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Gradation Evaluation of Asphalt Rubber Mixture with Warm-mix Additive

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Abstract

This paper addresses the effect of gradation on the high temperature performance and water stability of asphalt rubber mixture that contains Evotherm. The gradation of asphalt rubber mixtures was selected for the performance analysis of asphalt rubber mixture with warm-mix additive. The volumetric properties and performance of hot-mix and warm-mix asphalt rubber mixtures were investigated by Marshall Test, rutting test and freeze-thaw split test. The results indicated that the asphalt aggregate ratio played a critical role in determination of the feasibility of warm-mix process. The AR-AC-13 mixture was not suitable for warm-mix process due to the over high binder content. The warm-mix process was effective to improve the volumetric properties of AR-SMA mixture at lower mixing and compaction temperatures. The high temperature performance of AR-SMA mixture with Evotherm was ensured, while the water stability decreased somewhat.

Keywords: Asphalt rubber; warm-mix; gradation; stone matrix asphalt

1. Introduction

Previous studies have indicated that rubberized binders can produce asphalt pavements that exhibit decreased traffic noise, reduced maintenance costs and resistance to rutting and cracking. Because of these advantages, there is an increasing interest in utilizing rubberized binders in hot-mix asphalt pavement in China (Wang, 2000). The rubberized binder by wet process contains at least 18% crumb rubber modifier. Due to the high viscosity and thick binder film, the asphalt aggregate ratio is higher than conventional mixtures by 50% almost. As a result, the compaction temperature of asphalt rubber mixture should be higher than HMA. It is hard to build pavements in cold regions and climate using asphalt rubber mixtures. If the technologies of warm-mix asphalt are incorporated,

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it is predicted to observe a reduction in the mixing and compaction temperatures of rubberized asphalt mixtures compared to those of conventional mixtures.

Evotherm could form a lubricating layer between aggregates and binder and improve the volume properties and workability of conventional mixtures, reducing the mixing and compaction needed for production (Zhang, 2009; Qin, 2010). However, crumb rubber modifier particles have significant effect on the uniformity of binder and gradation of mixture. Asphalt rubber mixtures commonly use special gap gradations, such as AR-AC-13, AR-SMA (Ling, 2010). The properties of asphalt rubber mixtures with Evotherm are not studied in detail yet.

The effect of gradation on properties of asphalt rubber mixtures was compared in this study, based on the investigation of AR-AC-13 and AR-SMA mixtures with Evotherm. Some advice about the design of asphalt rubber mixture with Evotherm was given.

2. Materials and experiment Structure

2.1. Asphalt binder and warm-mix additive

The asphalt rubber produced with the PG 64-22 binder (base binder) and 20 mesh crumb rubber modified (ambient, truck) has good performance at a wide range of temperature, proved to be the PG 82-28 binder (Cao, 2008; Huang, 2010). The high temperature performance of asphalt rubber mixtures was significantly related to the 177℃ viscosity of binders. To ensure the rutting resistance of mixtures at high temperature, the binder with high viscosity is tend to be selected. However, the high viscosity of binders goes against the compaction of mixtures. To control the air void content is necessary to ensure the water stability of mixtures. The high viscosity of asphalt rubber at low temperature conflicts with the compaction of asphalt rubber mixtures. Above all, PG 64-22 base binder supplied by Sinopec Company and 20 mesh ambient crumb rubber modified were used to prepare the asphalt rubber binder with the viscosity of at least 3.0 Pa.s in this study.

The content of crumb rubber modifier in the asphalt rubber binder was 18%. The gradation of crumb rubber modifier was controlled and listed in Table 1, referred to Arizona standard specifications. The crumb rubber modifier binder was mixed with a stirrer (200-400 rpm) at 180℃ for 60min. This mixing condition matches the field practices used in California to produce field CRM mixtures. The properties of base binder and asphalt rubber are listed in Table 2.

Table 1 Gradation of crumb rubber modifier

Sieve size	Requirement % passing	Tested value %passing
NO. 8	100	100
NO. 10	95-100	96.7
NO. 30	0-10	6

Table 2 Conventional test results for binders

Binder designation	Base binder	Asphalt rubber
Apparent viscosity at 60℃ (Pa.s)	197	-*
Apparent viscosity at 177℃ (Pa.s)	-	3.3
Penetration at 25℃, 100g, 5s (0.1mm)	70.2	33.7
Softening point (%)	48.6	71.9
Ductility, 5℃ (cm)	-	6.3
Ductility, 15℃ (cm)	>100	-
Recovery, 25℃ (cm)	-	79.2

* Not available

The asphalt rubber mixtures with Evotherm DAT H5 were evaluated in this study. DAT H5 is a concentrated solution of water and chemical additives that is directly injected into binders. It contains 99% water by weight. DAT H5 acts on the interface between the aggregate and binder as a surfactant, having no influence of the viscosity of binder almost. DAT H5 was added at a rate of 10% by the weight of binder.

2.2. Aggregates

Two kinds of aggregates were used in this study. The basalt was used as coarse aggregate and limestone as fine aggregate. Base properties of aggregates were listed in Table 3.

Table 3 Basic properties of aggregates

Aggregate sort	Size (mm)	Crushed stone value (%)	LA abrasion (%)	Apparent specific gravity	Bulk specific gravity	Water absorption rate (%)
Basalt	13.2-16.0	-*	15.9	2.902	2.865	0.44
	9.5-13.2	13.9	15.9	2.896	2.854	0.59
	4.75-9.5	-	15.2	2.887	2.835	0.91
Limestone	2.36-4.75	-	21.4	2.708	2.684	0.89
	1.18-2.36	-	-	2.704	2.649	-
	0.6-1.18	-	-	2.702	2.590	-
	0.3-0.6	-	-	2.650	2.546	-
	0.15-0.3	-	-	2.694	2.583	-
	0.075-0.15	-	-	2.702	2.596	-

*Not available

2.3. Marshall mix design

The AR-AC -13 recommended by Arizona DOT proved good at the durability and economy and has been used in China in recent years. AR-SMA was put forward by Texas DOT, which has less binder and better high temperature performance. No mineral filler was used in the AR-AC-13 mixture, while 6.5% in the AR-SMA mixture.

Table 4 Gradation of asphalt rubber mixtures

Sieve size (mm)	AR-AC-13 Passing (%)	AR-SMA1 Passing (%)	AR-SMA2 Passing (%)
16.0	100	100	100
13.2	99.5	80	80
9.5	63.6	56.2	56.2
4.75	32	30	30
2.36	18.5	20	25
1.18	10	15	19
0.6	6.5	10	15
0.3	3.1	8	12
0.15	1.8	6	9
0.075	0	5	6.5

* Not available

2.4. Study of ease of compaction

The workability is significantly related to the ease of compaction of asphalt rubber mixtures. Volumetric parameters including air voids, voids in mineral aggregates and voids filled with asphalt, were selected to analyze the difference of ease of compaction between the AR-AC-13 and AR-SMA mixtures with Evotherm DAT H5.

Eight samples for each kind of mixture were fabricated by the Marshall method. Their averages of volumetric parameters were taken to reflect the ease of compaction.

2.5. Study of high temperature performance

Rutting resistance test was done for the study of high temperature performance. The wheel tracking test uses a square slab sample with a side 30 cm long and 5 cm thick. The specified air voids content of the slab specimen was controlled by controlling the amount of mixture in the specified steel mold. The target air voids content for the slab specimens was 4%. The finished slab was allowed to cool at room temperature for 12 h. It was then put into an oven at 60 ℃ for another 5 h before being placed into the wheel tracking device. The wheel tracking device was maintained at 60 ℃. The loading wheel was a piece of solid, hard rubber, 20 cm in diameter, with a width of 5 cm. The wheel weighed 70 kg and traveled back and forth at 21 rounds per minute. This is equivalent to pressing the slab 42 times per minute. We then recorded the depth of the track depression (rut depth) at various times. The DS can be computed as (N2-N1) / (d2-d1) with a unit of time/mm. A higher DS means better resistance to permanent deformation. For each of the two kinds of mixtures evaluated, we made four samples and took their averages to represent the rut resistance.

2.6. Study of water sensitivity

The three mixes were compacted to an average air void content of 6.0%. We prepared four Marshall Specimens for the dry group and four specimens for the wet group. A tensile strength ratio (TSR) of wet group to dry group, was computed from the results of the indirect tensile strength test at 25 ℃. The higher the TSR value, the less the strength should be influenced by the water soaking condition, or the more water-resistant it should be. Normal SMA Specification requires a TSR value of 70% or more.

3. Experimental results and discussion

3.1. Study of ease of compaction

The AR-SMA mixtures had more course aggregates and mineral filler than the AR-AC-13 mixture. Without mineral filler, the AR-AC-13 mixture needed more rubberized binder to fill voids in mineral aggregates. The mixing of the aggregates with the asphalt binders was conducted at temperatures recommended by the manufacturers of asphalt binder. The loose asphalt-aggregate mixtures were oven aged at the average compaction temperatures for 2 h prior to the compaction. The properties of three mixtures without Evotherm DAT H5 were listed in Table 5.The figure number and caption should be typed below the illustration in 8pt and left justified. For more guidelines and information to help you submit high quality artwork please visit: http://www.elsevier.com/wps/find/authorsview.authors/authorartworkinstructions. Artwork has no text along the side of it in the main body of the text. However, if two images fit next to each other, these may be placed next to each other to save space, see Fig 1. They must be numbered consecutively, all figures, and all tables respectively.

Table 5 Properties of hot-mix asphalt rubber mixtures

Item	AR-AC-13	AR-SMA1	AR-SMA2
Mixing temperature (℃)	180~190	180~190	180~190
Compaction temperature (℃)	170~180	170~180	170~180
Optimum asphalt content (%)	8.3	7.2	6.1
Air voids (%)	4.5	4	3.4
Voids in mineral aggregates (%)	21.5	19.2	16.9
Voids filled with asphalt (%)	61.5	80.2	79.6

The AR-AC-13 mixture had the highest voids in mineral aggregates (VMA) and lowest voids filled with asphalt (VFA). The AR-SMA mixture was relatively easy to compact. The harder to be compacted, the higher optimum asphalt content (OAC) to be needed. The mineral filler is necessary for asphalt rubber mixtures to ensure the ease of compaction. However, the VMA is an important parameter to avoid bleeding of mixtures in the field. The 2.36 mm sieve is the critical one that influences VMA of mixtures significantly. For modified SMA mixtures, the VMA must be bigger than 16%. With respect to crumb rubber modifier particles in the rubberized binder, the higher VMA is needed to contain those particles. Otherwise, they may have adverse effect on the gradation of mixtures. The specifications of Texas recommended the VMA of AR-SMA bigger than 19%.

The mixing and compaction temperatures of 160 and 150°C were selected to evaluate the effect of warm-mix additives at relatively lower temperature. The results indicated that the AR-AC-13 mixture having the highest asphalt content was hard to compact. When the mixing and compaction temperature were respectively decreased to 160 and 150°C, the air voids of AR-AC-13 mixture with Evotherm DAT H5 increased from 4.5% to 6.4%. Nevertheless, the ease of compaction of AR-SMA mixtures with warm-mix additive was not affected significantly by temperature. The viscosity of rubberized binder increases with the temperature decreasing. Although Evotherm DAT H5 could improve the compaction of mixtures to a certain extent, over high binder content will lead to poor volumetric properties at the relatively lower compaction temperature. The use of mineral filler could be considered to reduce the asphalt content of asphalt rubber mixtures.

The VMA of asphalt rubber mixture should be controlled in order to increase the VFA. The VFA must be greater than 70% to ensure the density of mixture. If not, the interlock of aggregates will not be good enough. The high temperature performance of AR-AC-13 may be worse than AR-SMA mixtures.

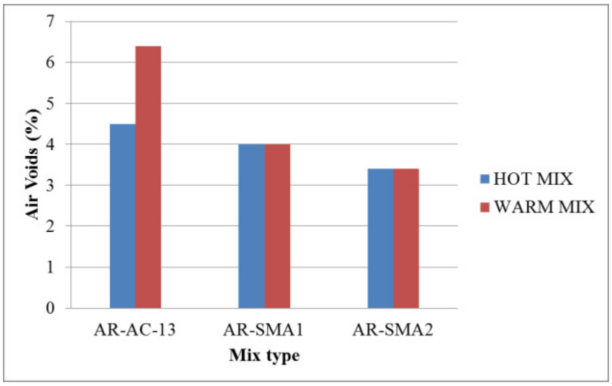

Fig. 1. Air voids of hot-mix and warm-mix asphalt rubber mixtures

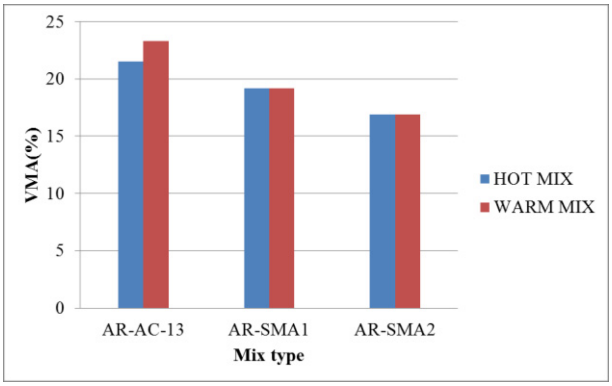

Fig. 2. VMA of hot-mix and warm-mix asphalt rubber mixtures

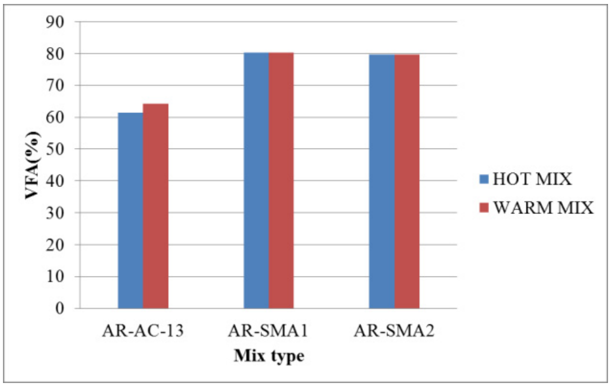

Fig. 3. VFA of hot-mix and warm-mix asphalt rubber mixtures

3.2. Study of high temperature performance

The temperature conditions of preparing square slab samples were as same as Marshall Samples in the compaction test. The results indicated that the dynamic stability of hot-mix asphalt rubber mixtures was greater than mixtures with warm-mix additive (Fig. 4). The optimum asphalt content and VMA of AR-SMA2 mixture were lowest, while the dynamic stability and VFA was highest of all three mixtures. Despite the volumetric properties of warm-mix AR-SMA mixtures were nearly unchanged compared with the hot-mix mixtures, the adhesion force of binder may be decreased as a result of compaction of mixtures at the lower temperature.

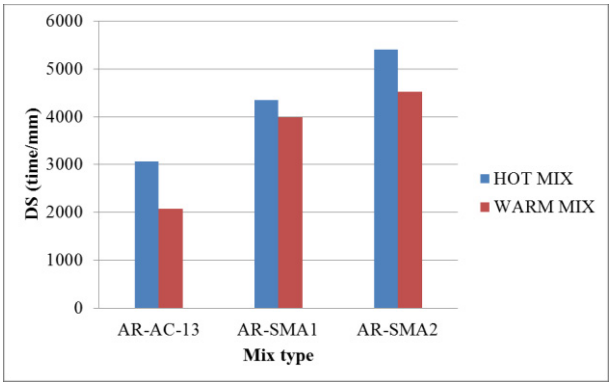

Fig. 4. Dynamic stability of hot-mix and warm-mix asphalt rubber mixtures

3.3. Study of water sensitivity

The TSR value, which represents the moisture susceptibility, is affected significantly by the air voids of mixtures. The TSR value of AR-AC-13 mixture with Evotherm DAT H5 decreased significantly duo to the much higher air voids than the hot-mix mixture. The AR-SMA mixtures had higher TSR values than the AR-AC-13 mixture (Fig. 5). Evotherm DAT H5 is a kind of hydrophilic surfactants as well. Although the water sensitivity of three hot-mix mixtures was greater than 80% and volumetric properties of AR-SMA mixtures with Evotherm DAT H5 had almost no changes compared with hot-mix mixtures, the TSR values decreased. However, the AR-SMA1 mixture with Evotherm DAT H5 had the TSR value between 70 and 80% and was close to the lower limit.

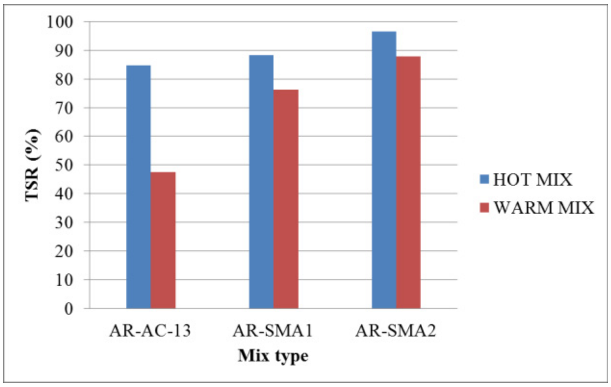

Fig. 5. TSR of hot-mix and warm-mix asphalt rubber mixtures

4. Conclusions

The following conclusions can be drawn based on the limited experimental data and in accordance with the related properties of the mixtures tested for this study:

1. The addition of Evotherm DAT H5 reduced the mixing and compaction temperature of asphalt rubber mixtures, which was significantly affected by the optimum asphalt content of mixture. The AR-AC-13 mixture was not suitable for warm-mix process due to the over high binder content. The warm-mix process was effective to improve the volumetric properties of AR-SMA mixture at lower mixing and compaction temperatures.
2. The AR-SMA mixtures with Evotherm DAT H5 having less binder were easier to be compacted at a lower temperature compared with the AR-AC-13 mixture. Therefore, they had better rutting resistance and water stability than the warm-mix AR-AC-13 mixture. The AR-SMA is suitable for the warm-mix process. However, the hot-mix AR-AC-13 mixture proved to having good pavement performance as well.
3. The warm-mix asphalt rubber mixtures with Evotherm DAT H5 performed worse than hot-mix mixture in high performance test and water sensitivity test. Although volumetric properties of war-mix asphalt rubber mixtures had almost no changes compared with hot-mix mixtures, the adhesion force of binder seemed not to be ensured by the warm-mix additive.

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